

For: GRL

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## North-Atlantic Surface Winds Examined as the Source of Winter Warming in Europe

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**Abstract** When from the southwest, North Atlantic ocean surface winds are known to bring warm and moist airmasses into central Europe in winter. By tracing backward trajectories from western Europe, we establish that these airmasses originate in the southwestern North Atlantic, in the very warm regions of the Gulf Stream. Over the eastern North Atlantic, at the gateway to Europe, the ocean-surface winds changed directions in the second half of the XXth century, those from the northwest and from the southeast becoming so infrequent, that the direction from the southwest became even more dominant. For the January-to-March period, the strength of southwesterlies in this region, as well as in the source region, shows in the years 1948-1995 a significant increase, above  $0.2 \text{ m s}^{-1}$ /decade. Based on the sensitivity of the surface temperature in Europe, slightly more than  $1^\circ\text{C}$  for a  $1 \text{ m s}^{-1}$  increase in the southwesterly wind, found in the previous studies, the trend in the warm advection accounts for a large part of the warming in Europe established for this period in several reports. However, for the most recent years, 1996-2001, the positive trend in the southwesterly advection appears to be broken, which is consistent with unseasonally cold events reported in Europe in those winters. This study has some bearing on evaluating the respective roles of the North Atlantic Oscillation and the Greenhouse Gas Global warming, GGG, in the strong winter warming observed for about half a century over the northern-latitude continents. Changes in the ocean-surface temperatures induced by GGG may have produced the dominant southwesterly direction of the North Atlantic winds. However, this implies a monotonically (apart from inherent interannual variability) increasing advection, and if the break in the trend which we observe after 1995 persists, this mechanism is counterindicated. The 1948-1995 trend in the southwesterlies could then be considered to a large degree attributable to the North Atlantic Oscillation.

## 1. Introduction

The term North Atlantic Oscillation, NAO, for the fluctuation of the difference in the sea-level pressure between Iceland and the Azores was introduced by Walker (1924). A similar concept of climate oscillation but suggesting a symmetry about the pole, commonly called today the Northern-Hemisphere Annular Mode, NAM, was introduced later by Rossby (1939), formulated in terms of temperate-latitude westerly winds, at the surface or aloft. Focussing on the Pacific, Namias (1950) defined the oscillation in terms of the difference between the westerlies at  $55^{\circ}\text{N}$  and  $35^{\circ}\text{N}$ . Van Loon and Rogers (1978), and later Hurrell (1995) and Rogers (1997), pointed out the dominant role of the ocean-to-land advection as modulated by the NAO/NAM oscillation on the climate conditions, especially winter temperatures, in Eurasia and North America.

Thompson et al. (2000), and Wallace and Thompson (2002) discussed in depth the NAO/NAM phenomena, in terms of the surface pressure records. As an extension of such studies, we analyze for the second half of the XXth century the North Atlantic surface winds as the control of winter temperature in Europe. Thus, up to a point, we revert here to the ocean- surface wind analysis, the original approach of Rossby (1939) and Namias (1950). However, we focus here on the influence of these winds on the winter temperature in Europe. Based on our previous studies, and the analysis given here of the source-area from which the warm-advection into Europe originates, we stress the westerlies with a southerly meridional component, that is, the southwesterlies, inasmuch as the northwesterlies can have a different impact. This becomes obvious from inspecting Fig. 1, of surface temperature for February 1990, which shows the eastern North Atlantic surface above  $55^{\circ}\text{N}$  much colder than below this latitude.

## 2. Source-areas of warm advection into Europe.

To identify the source-areas of the airmasses that on entering Europe produce elevated surface-air temperature, we examine here the ocean-atmosphere heat exchanges. When February mean wind over the eastern North Atlantic is from the southwest, the monthly mean sensible heat flux from ocean in these areas takes slightly negative values, that is, the surface-air is slightly warmer than the ocean. In Fig. 2, for February 26, 1990, 00Z, we present backward- traced trajectories from that time up to fourteen 6-hour intervals earlier. These trajectories overlay an elongated area of negative values for the temperature difference between 2 m air and the surface. Thus, Fig. 2 indicates that the warm airmasses that flow into Europe originate in the southwest North Atlantic, below  $40^{\circ}\text{N}$ , roughly between  $35$  and  $55^{\circ}\text{W}$ . This area is just to the east of the warmest sections of the Gulf Stream, and we note extreme temperature gradients with latitude, see Fig. 1. The isotherms shift northward toward the east and thus temperature differences between this region and east North Atlantic,  $55$  and  $45^{\circ}\text{N}$ , the gateway to Europe, are actually small. Note, however, that the temperatures near Iceland (which is much closer to France than our source-areas) are much lower, below  $4^{\circ}\text{C}$ . In crossing the Atlantic in the southwesterly low-level flow, the airmasses, to some extent (the temperature differences between the surface-air and the ocean are small) lose heat to the surface.

To analyze what can be called the “advection-into-Europe-index”, we examine (in the next section) southwesterlies in areas at the beginning and near the end of the trajectories.

### 3. North Atlantic winds, 1948-2001

For assessing the trends in the North Atlantic surface winds we rely on the NCEP/NCAR Reanalysis, which is available beginning from 1948. Southwesterlies, SW, are computed as  $SW = (W^2 + M^2)^{1/2}$ , where  $W$  is the zonal component and  $M$  the meridional component, only if  $W$  is westerly and  $M$  is zero or southerly (if  $M$  is northerly,  $SW=0$ ). We divided the 1948-to-1999 period into the first half, FH, and the second half, SH, and evaluated the frequency of the February average wind in different quadrants. SW quadrant was dominant in the FH, but even more so in the SH, in which the winds were SW for 24 Februarys at 45°N; 30°W, and for 19 Februarys at 45°N; 20°W(out of 26), see Table 1.

Also from NCEP/NCAR, we examine the strengths of the SW vs. the year of the Reanalysis, 1948-2001, in nine North Atlantic locations. For each pentad (5-day period) and each year, we evaluate SW from  $W$  and  $M$  as described above, and then calculate average SW for 18 pentads, January to March, for each year. In the eastern North Atlantic the three plots at 20°W are presented as Fig. 3A, and the three plots at 30°W as Fig. 3B, in each case at 55, 45 and 35°N. We note that whereas SW at the latitudes 55 and 45°N show rising trends for the 1948-91 period, the trend of SW at 35°N (which exhibits a negative correlation with SW at 45 and 55°N) is negative. Thus, the concept of a zonal circulation index that Namias (1950) developed as the difference in the westerlies between latitudes 55°N and 35°N, suggests itself now as an interesting southwesterly-advection index. The 1948-95 trend in 3 out of 4 more northerly locations (55 and 45°N) is in the 0.22 to 0.4 m s<sup>-1</sup>/decade range. SW in three locations in the source area from where we traced the trajectories at 35, 45 and 50°W, all at 40°N (Fig. 2) are presented as Fig. 3C. The 1948-95 trend in the two western locations is 0.22 m s<sup>-1</sup>/decade, with only slight positive value in the eastern location. As we discuss (with caveats) in the next

section, such trends in the SW account for a large part of the winter warming observed in Europe over this 47-year long period.

With a caveat of another nature, that trends can be established only from long term records, we observe a break in the trend-line, a discontinuity starting in 1996, in each of the nine plots in Figs. 3A, B, C. This break appears to be strongly related to the downturn in recent years of the NAM indices discussed by Thompson et al. (2000) and Wallace and Thompson (2002). Unseasonably cold-winter events were reported from Europe in the most recent years (Przybylak et al., 2002), apparently resulting from this trend reversal (even though the 1996/97 winter was rather warm).

#### **4. Discussion and conclusions**

We analyzed the patterns and trends in the North Atlantic surface winds for the second half of the XXth century, in order to assess the role of maritime-air advection in the well-established (Angell, 1999; Hansen et al., 1999) winter warming in Europe. With this aim, we studied the southwesterlies, since it is the winds from that direction (rather than westerlies in general) which bring warm and moist air into Europe. That this is the direction from which the warm flow arrives to the western coasts of Europe is well illustrated by the backward-traced trajectories, that point to the southwestern North Atlantic as the source-areas.

For analyzing the 1948-2001 trends in the southwesterlies we apply the NCEP/NCAR dataset. A discontinuity might have been introduced into the Reanalysis in 1974, when satellite measurements became available (Kalnay et al., 1996; Kistler et al., 2001). The problem may not be substantial in the case of the ocean surface winds over the North Atlantic, where ample meteorological data from coastal stations and ship data are available, but some uncertainty remains. We found the southwesterlies increasing at

the rate 0.22 to 0.4 m s<sup>-1</sup>/decade in three locations out of four at 55 and 45°N, 10 and 20°W, and 0.22 m s<sup>-1</sup>/decade in two (out of three) locations in southwestern North Atlantic, at 40°N. Increasing strength of the eastern North Atlantic surface winds is consistent with the changes in the wind waves reported (for somewhat shorter periods) by Kushnir et al. (1997) and Gulev and Hess (1999).

With the above caveats, based on the sensitivity of the winter surface temperature in central Europe of slightly more than 1°C per 1m s<sup>-1</sup> increase in the southwesterlies inferred in previous studies from a much shorter period, 1988 to 1997, of Special Sensor Microwave/Instrument, SSM/I, observations (Otterman et al., 1999; Otterman et al., 2002), the trend in the maritime-air advection accounts for more than half of the reported warming of nearly 0.5°C/decade (Angell, 1999; Hansen et al., 1999). Such low-level advection inherently makes the lapse rate steeper, which is consistent with the reports (Ross et al., 1996; Angell, 1999) that the trends at higher tropospheric levels are of the same sign as at the surface, but of reduced magnitude. Moisture is available, and enhanced cloud-cover (especially high clouds) is a corollary effect to the steeper lapse rate (Otterman et al., 2002). Indeed, increased cloudiness is reported for this period, see Keevalik and Russak (2001), for instance. That these two trends which inherently accompany the near-surface warming by low-level warm advection actually are observed, strengthens the case for attributing the warming to this process.

Changes in the ocean-surface temperatures induced by GGG may have produced the dominant southwesterly direction of the North Atlantic winds. However, this implies a monotonically (apart from inherent interannual variability) increasing advection, and if the break in the trend which we observe after 1995 persists, this mechanism is counterindicated. The 1948-1995 trend in the southwesterlies could then be considered to a large degree an aspect of the North Atlantic Oscillation.

Our analysis of the wind trends suggest further studies. In studying the interannual variability of southwesterlies (for the period of SSM/I data), Otterman et al. (1999) observed that, not surprisingly, the entire troposphere over the North Atlantic participates in the fluctuations, exhibiting a see-saw oscillation between western and eastern locations of the North Atlantic. In the weak-southwesterlies Februarys (cold Europe) (a) the surface-air temperature difference between the west (65-45°W) and the east (25-5°W) was large, whereas negative in the strong-southwesterlies Februarys, and (b) the difference between the 500 mb meridional wind in the west and that in the east was positive and large (exceeding  $10 \text{ m s}^{-1}$ ), but became negative and small in the strong-SW Februarys. What decadal trends characterize these differences in the 1948-1995 period?

Lucarini and Russell (2000) establish the validity of the GGG simulations by their two atmosphere-ocean climate-models by comparing the derived climate trends of the temperatures at various levels with the NCEP Reanalysis. It would be most interesting to analyze and report the trends or changes in the ocean-surface wind fields in such climate simulations. Lucarini and Russell (2000) present a detailed analysis of how to validate determination of a climatic trend, which we do not attempt. We plan to analyze the long record of NAO (available starting in 1874) to examine the transitions from ascending sections of the index to descending, to compare with the reversal from the 1948-95 trend that possibly occurred in 1996.



	45°N, 30°W		45°N, 20°W	
	1948-1973	1974-1999	1948-1973	1974-1999
Southwest	18	24	12	19
Northwest	2	0	7	4
Northeast	2	0	2	1

Table 1. Number of years that the average February surface wind direction was from the specified quadrant, for two eastern North Atlantic sites over two 26-year periods: 1948-1973, and 1974-1999.

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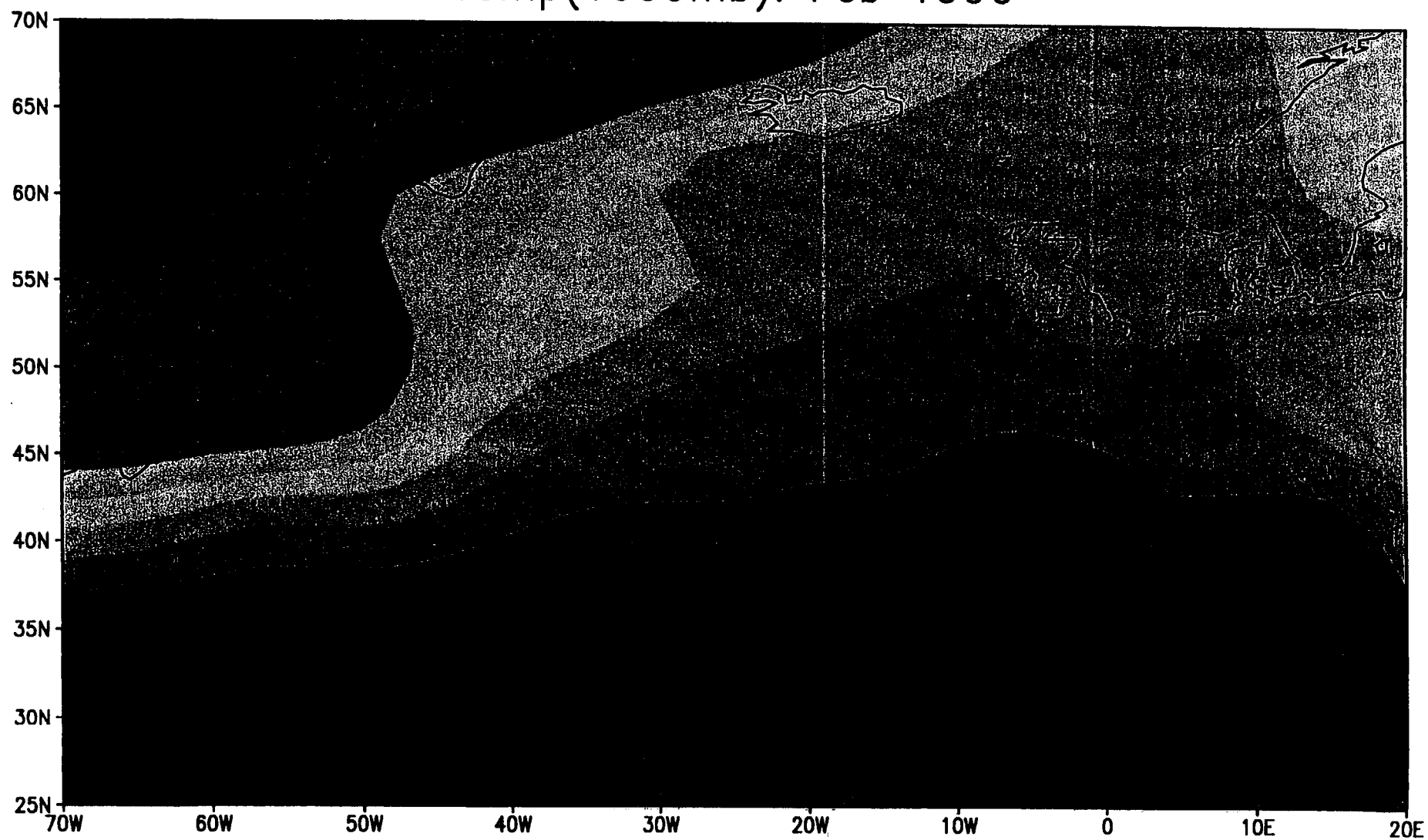
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Fig. 3. January to March averages versus the year of the NCEP Reanalysis; southwesterlies SW computed for each pentad,  $SW=(W^2 + M^2)^{1/2}$ , where W is the zonal wind and M the meridional wind, only if W is westerly and M is zero or southerly (if M is northerly, SW=0); three locations, at 20°W in Fig. 3A; three at 30°W in Fig. 3B; southwestern North Atlantic at 40°N, in Fig. 3C.

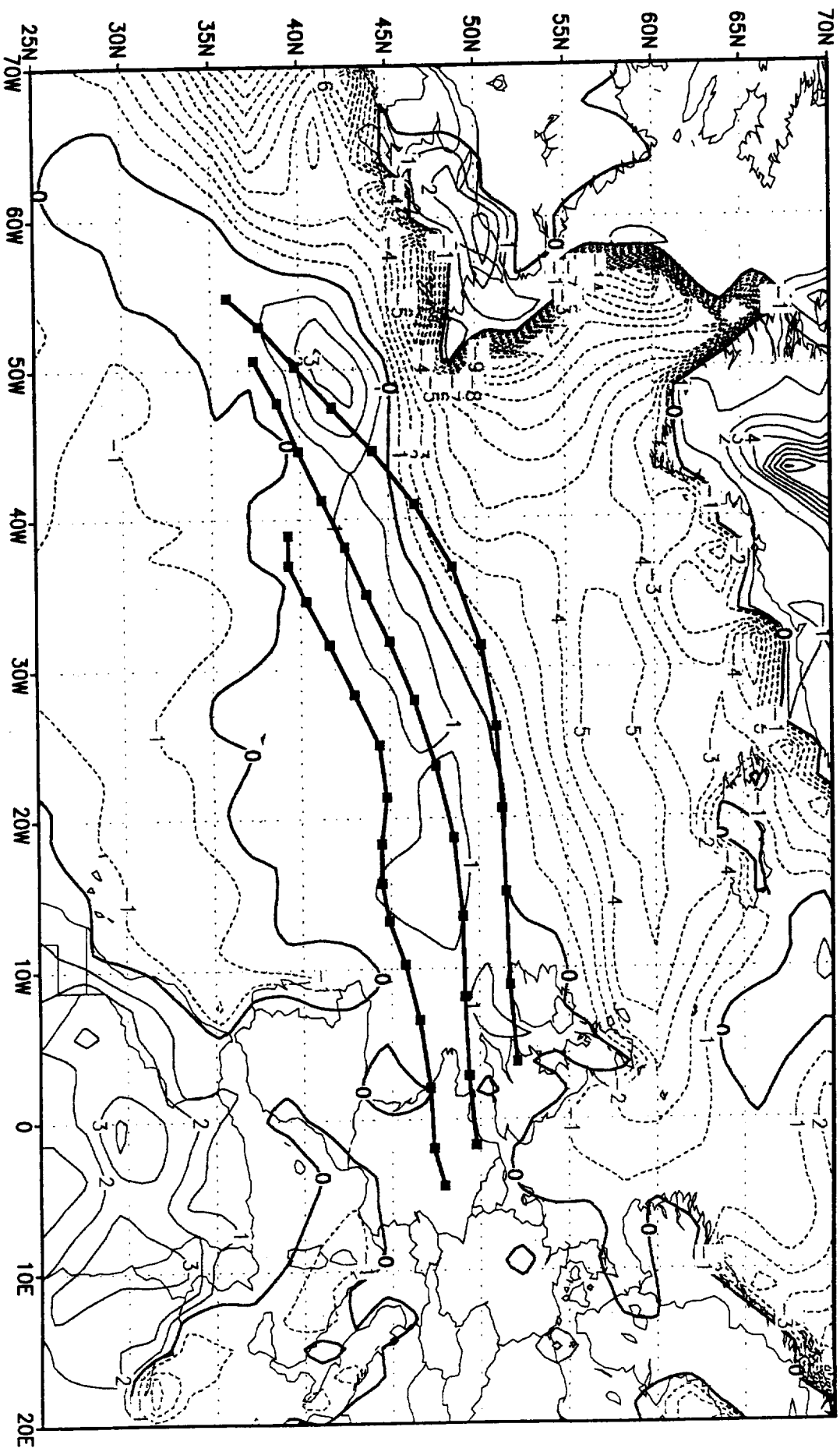
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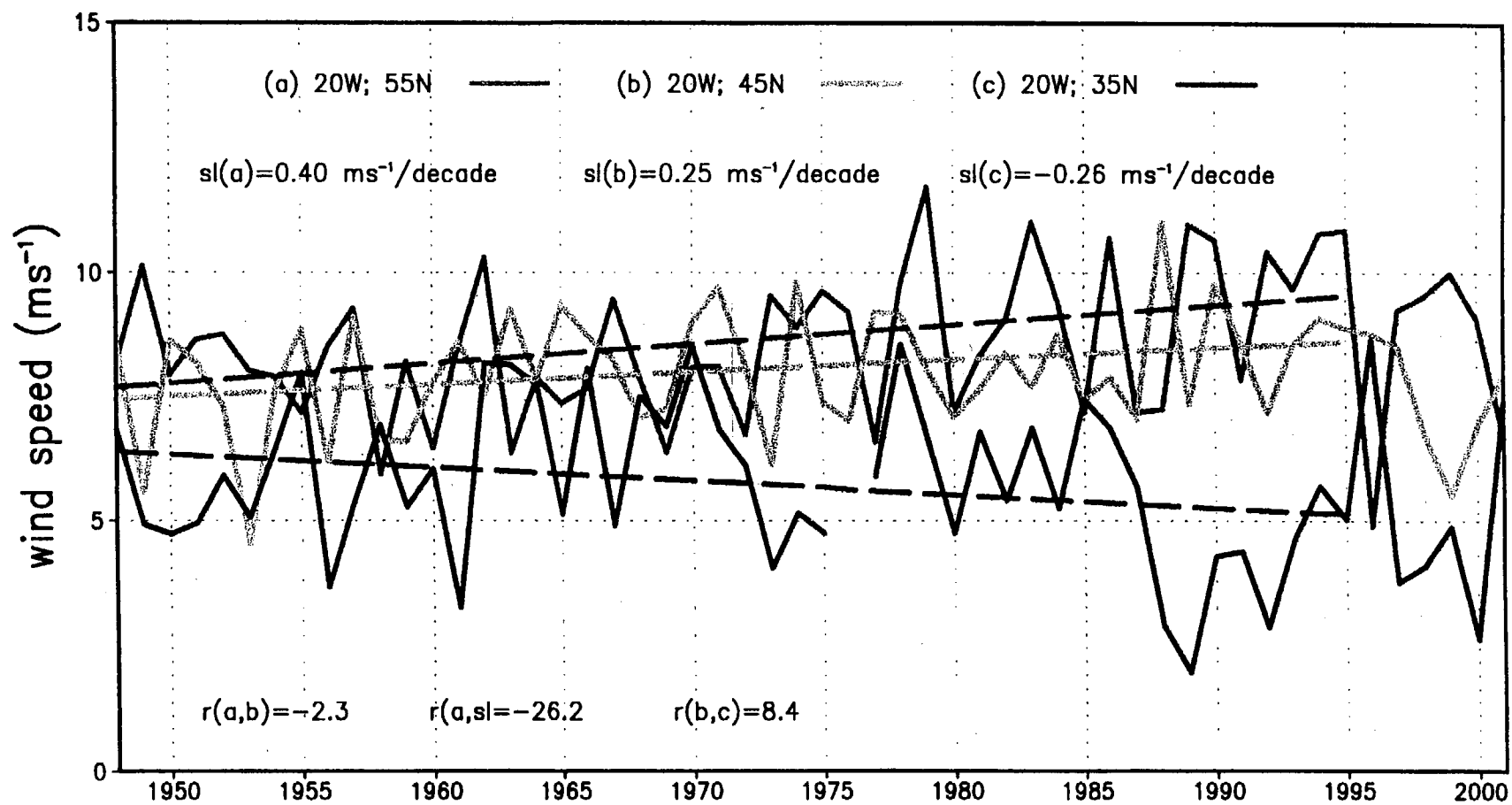
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Fig. 1

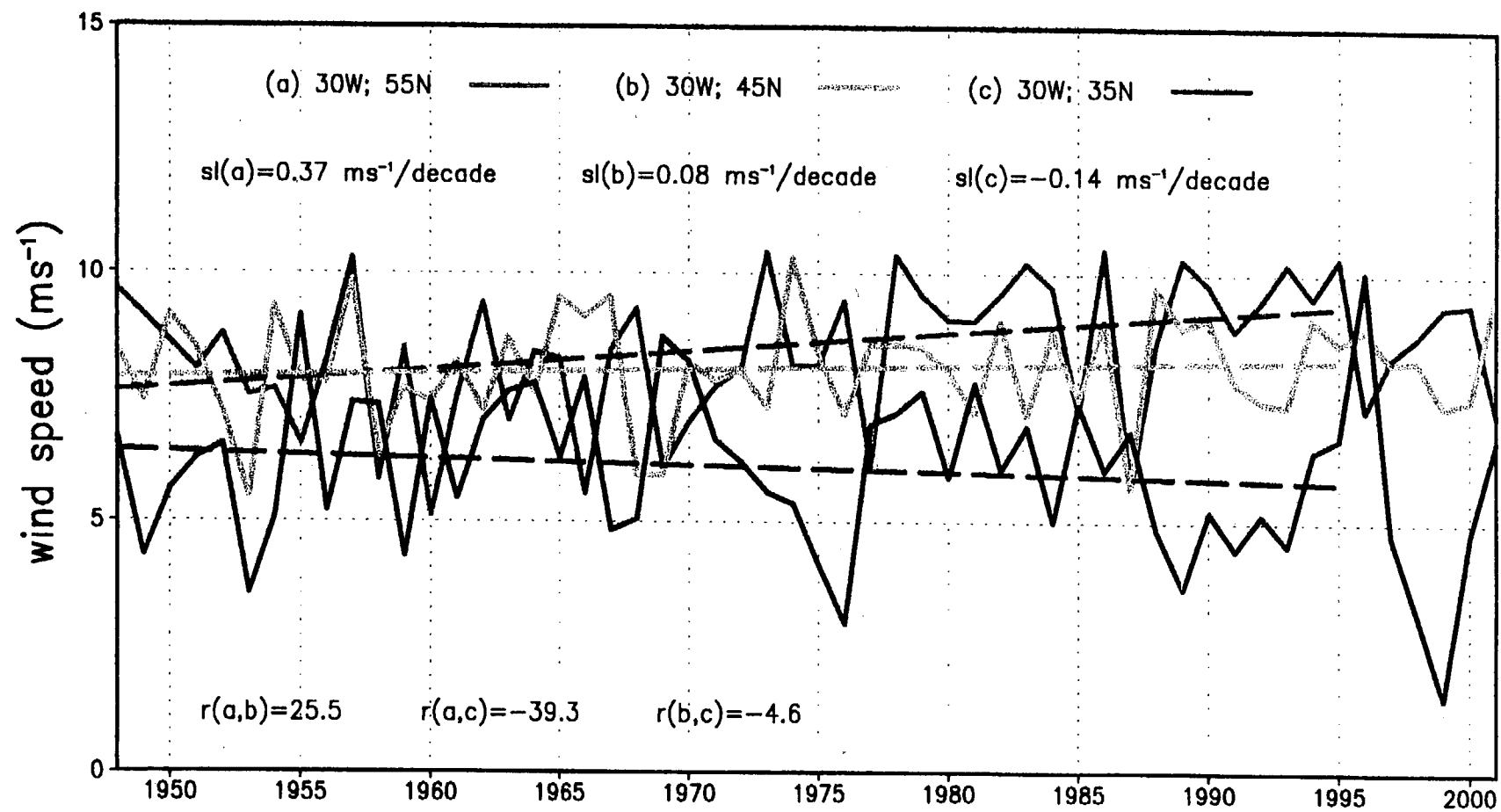
NCEP 2 m Temperature Minus Surface Temperature with Trajectories  
February 26, 1990 00Z



January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001

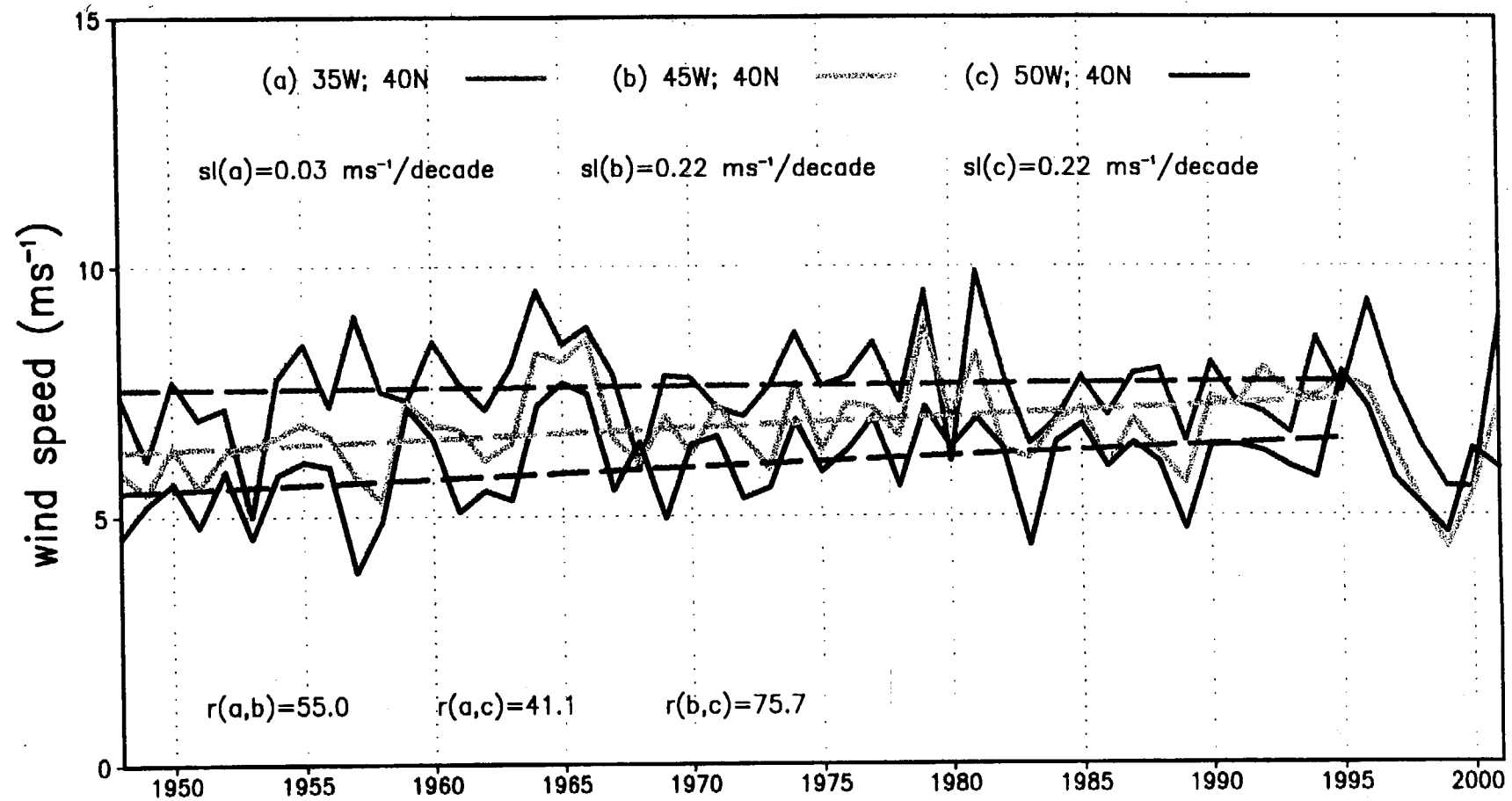


January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001

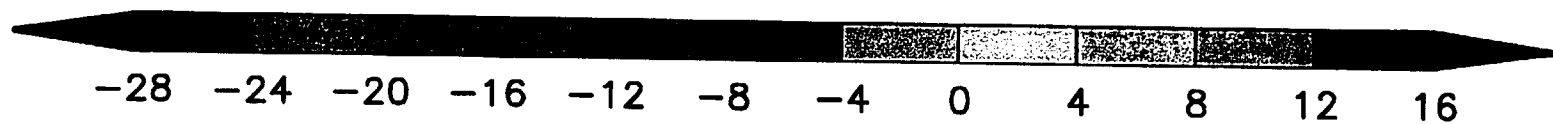




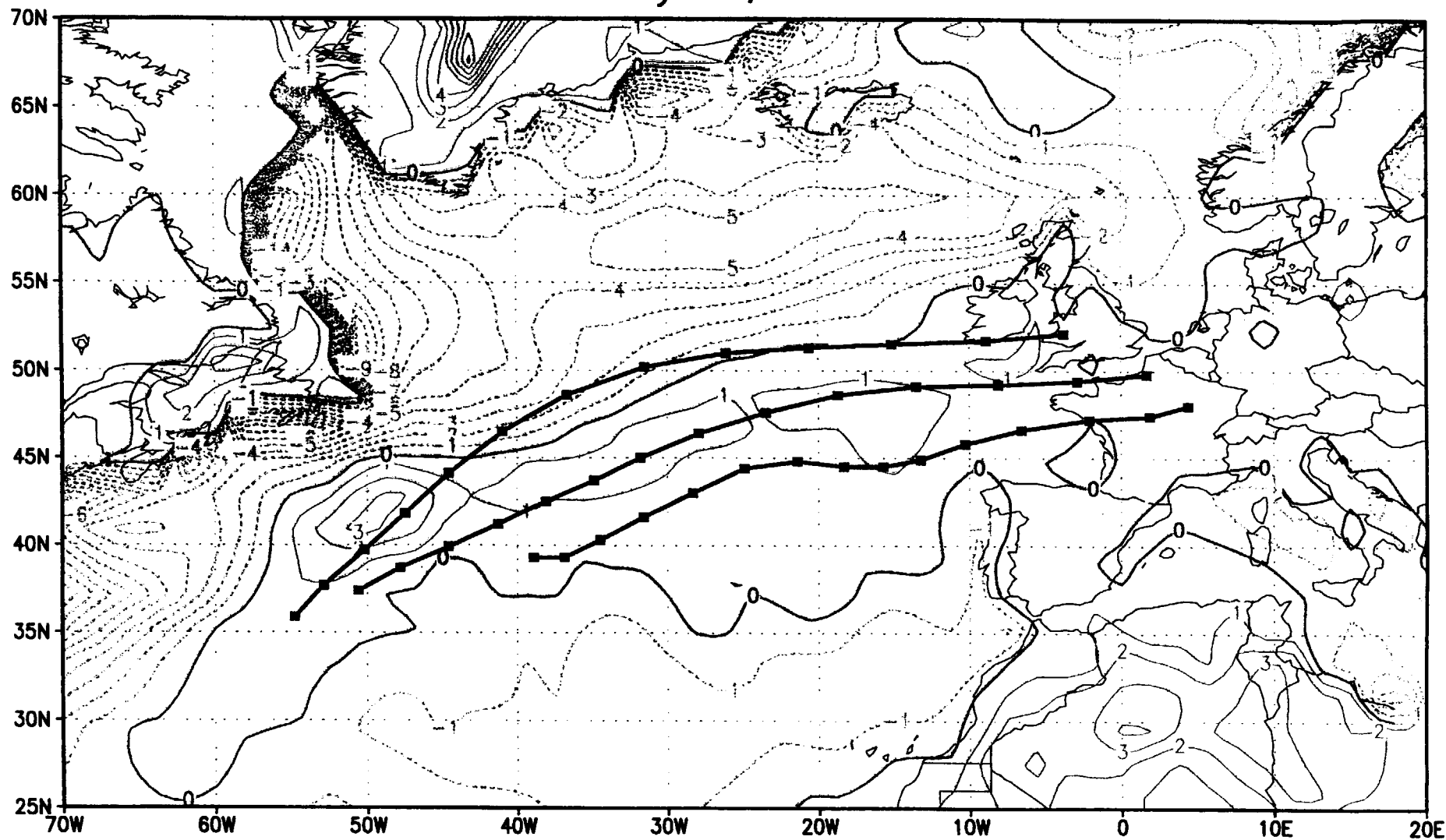
January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001



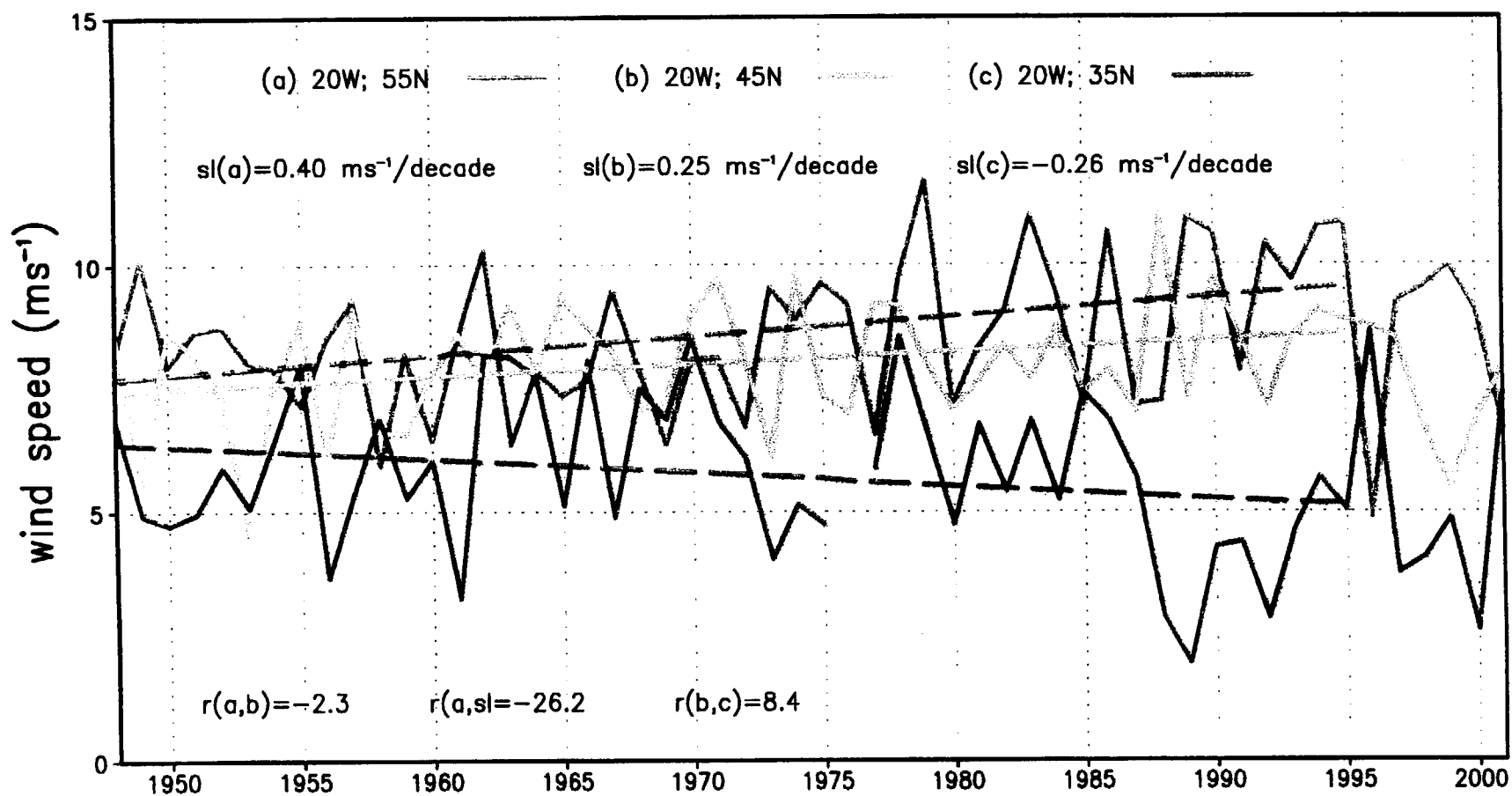
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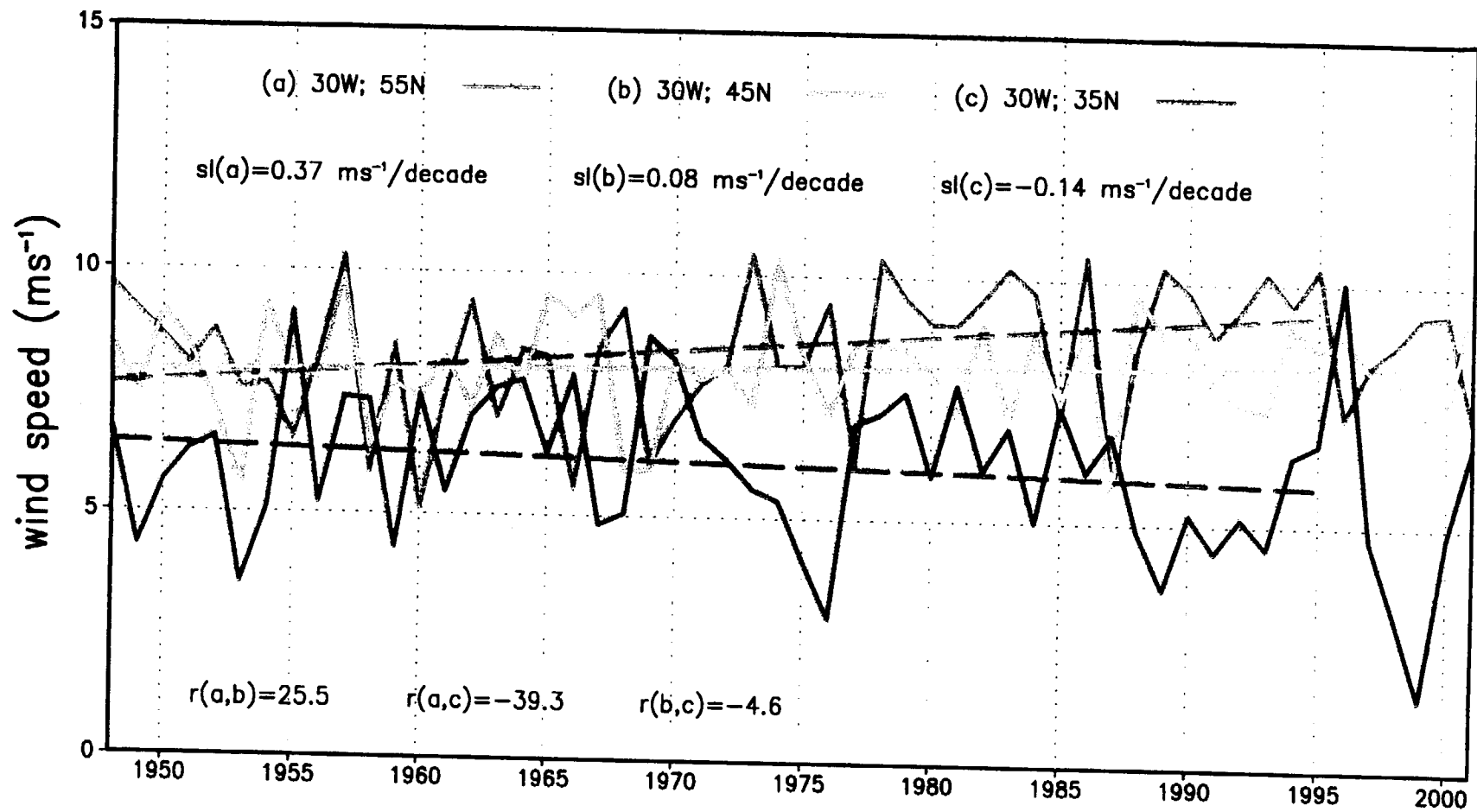
# NCEP 2 m Temperature Minus Surface Temperature with Trajectories February 26, 1990 00Z



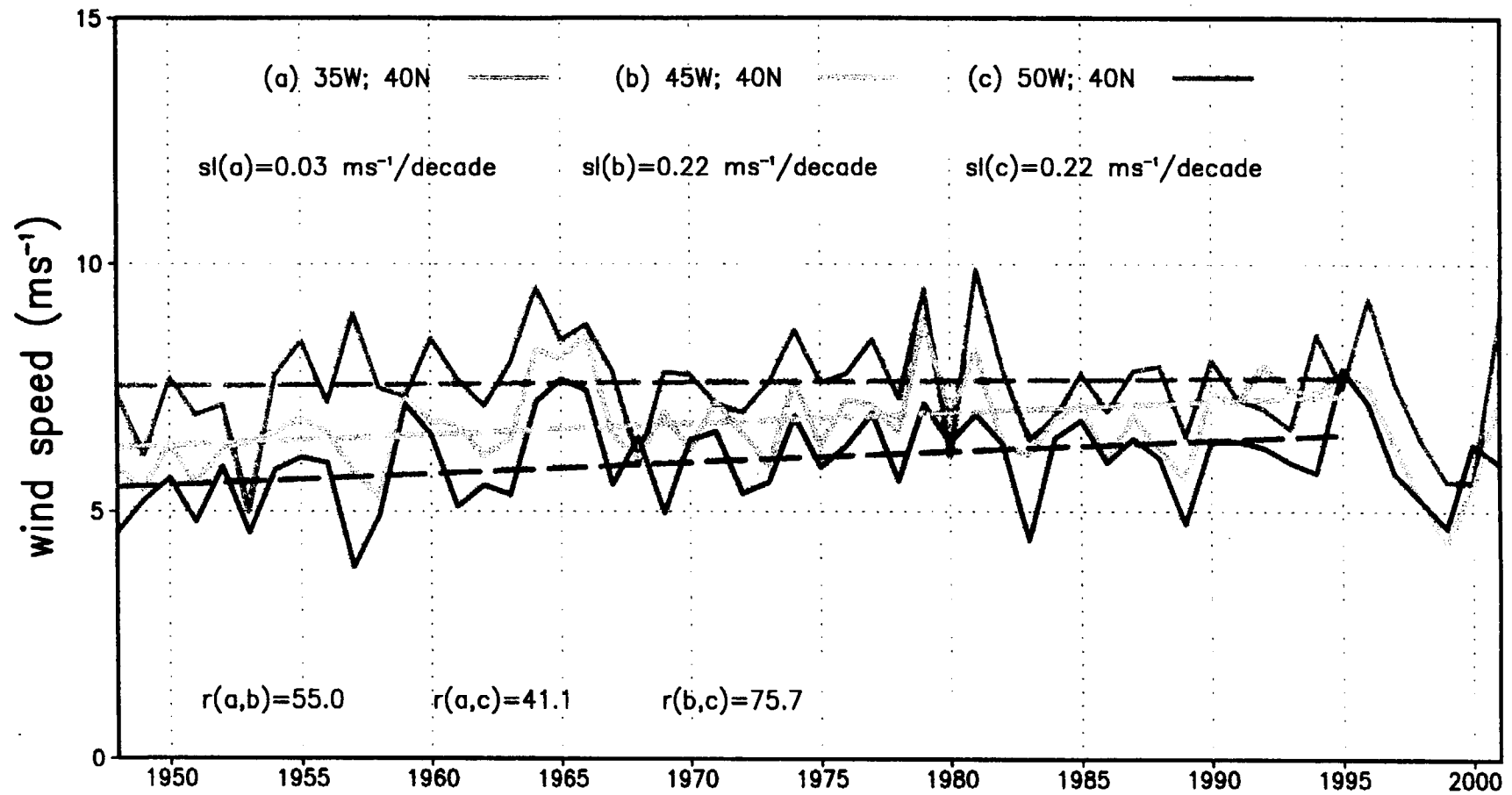
January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001



January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001



January\_March Mean Southwesterly Wind Speed ( $\text{ms}^{-1}$ ) at 10m 1948–2001



3.7 C